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TRANSPORTATION PLANNING MODELS: A SYNTHESIS OF VARIOUS USES

by

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ABSTRACT

This paper puts forward the view that, for each transportation planning or management problem, there is a **particular way** to simultaneously define the multiple levels of procedures useful for the problem and set it in its proper perspective, the latter essentially by the identification of what is exogenous and endogenous to the problem at hand. The joint determination of these levels and of the exogenous/endogenous mix defines the two-dimensional frame of each problem. To develop our view, we extend our previous conceptual framework to include, in the first dimension, an **activity location procedure**, and to distinguish, in the second dimension, between **operational, tactical** and **strategic perspectives.** We conclude by relativising the use of solution techniques by making them ancillary to the situation planning requirements.

Keywords : transportation planning, activity location, demand, supply, performance, cost minimization, operational, tactical, strategic.

RÉSUMÉ

Nous suggérons que, pour chaque problème de planification des transports, il y a une façon particulière d'utiliser les niveaux divers des procédures de **demande**, de **performance**, d'**offre** et de **minimisation des coûts** tout en déterminant simultanément ce qui est endogène et exogène au problème considéré. Pour préciser les tâches impliquées dans la première dimension, celle des niveaux de procédures, nous étendons aux procédures de **localisation des activités** l'ensemble de procédures déjà précisé dans des travaux antérieurs; dans la seconde dimension, nous utilisons les notions de perspectives **opérationnelle, tactique et stratégique** pour rendre concret le cadre de chaque problème. Nous sommes conduits à relativiser l'usage d'algorithmes de résolution en les rendant auxiliaires du cadre propre à chaque problème.

Mots-clefs : planification des transports, demande, offre, performance, minimisation des coûts, opérationnel, tactique, stratégique.

CONTENTS

1. The specification of transportation planning problems. 1

2. The "levels" dimension 2

A. Activity location and transportation procedures. 2

B. Five transportation procedures - a reminder. 3

C. The normative/descriptive and other casual distinctions. . . 5

3. The "perspectives" dimension 5

4. Towards a situation planning paradigm 12

References 16

Figure 1. Activity location and transportation systems. 2

Figure 2. Transportation systems analysis : five procedures 4

Figure 3. A two-dimensional conceptual framework. 9

1. THE SPECIFICATION OF TRANSPORTATION PLANNING PROBLEMS

In this paper, we ask what it is to specify a transportation planning problem. We present the view that problem specification is usefully broken down into problem framing and problem resolution. We hold that :

> To frame a transportation planning problem is simultaneously
> i) to identify the appropriate location-demand-performance-supply-cost minimization-production levels for the situation at hand, and
> ii) to adopt a perspective that determines what is endogeneous and exogeneous to the situation.

PROP 1

Conversely, we propose that this identification of what is demand, or supply, etc. and the determination of the endogenous/exogenous mix of factors constitutes a complete two-dimensional problem frame. Naturally, problem resolution is required to complete a problem specification :

> To resolve a transportation planning problem is to choose the precise model-specific functional relationships and computational algorithms that produce an acceptable answer for a particular frame.

PROP 2

The joint use of a frame and a resolution completely specifies **procedures**, where each is as previously defined by two of the present authors (Florian and Gaudry, 1980, 1983), namely as "a mapping which may consist jointly of one or more models and their algorithmic output".

Our emphasis here consists of explicating PROP 1 by developing each of the two dimensions involved — the levels and the perspectives — . Development of the **"levels"** dimension will involve extending the number of levels beyond that considered in the previous papers to consider an **activity location procedure.** Development of the **"perspectives"** dimension will involve clarification and enrichment of what is exogenous

and endogenous for the relevant horizon" (op. cit., 1983). The next two sections will each be assigned to the examination of a dimension. We will conclude the discussion with a "situation planning paradigm".24v

2. THE "LEVELS" DIMENSION

A. Activity location and transportation procedures

The first dimension taken into account in framing a transportation planning or management problem is that of deciding, for the problem at hand, which of the multilevel system components are of interest. Figure 1 shows a first set of candidate levels, starting with the **activity location procedure** and, jointly, **demand and performance procedures.**

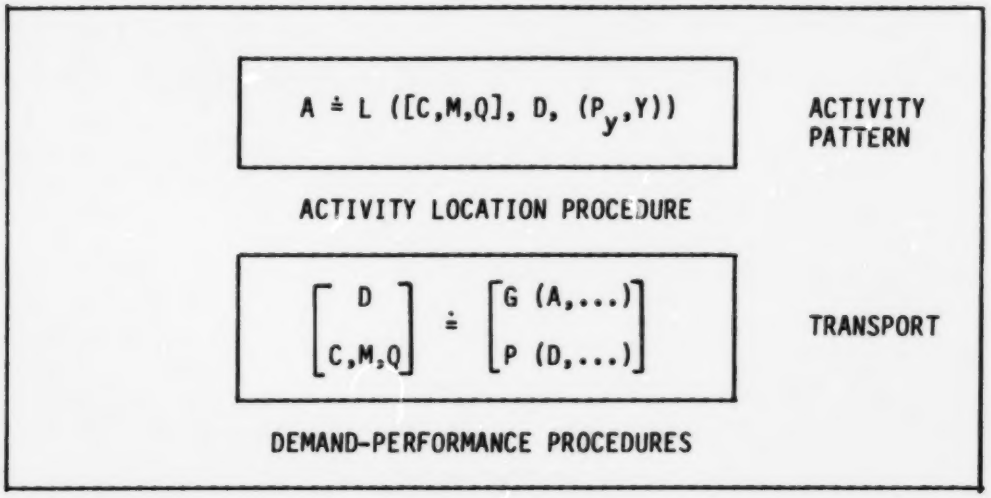

Figure 1. Activity location and transportation systems

In a location planning model, the level and distribution of activities in space A is derived from transportation network demand D, service levels C, out-of-pocket expenditures M and practical capacities Q; in addition, all other prices P_y in the economy, and the set of all other final and intermediate economic activities Y, are generally relevant in an **activity location procedure L.**

The actual transportation performance characteristics [C,M,Q] and the transportation quantities D are determined from all factors relevant in the **demand procedure G**, notably the activity pattern A itself, and factors involved in the **performance procedure P**, notably the demand D. Typically, models determine either the activity location pattern A or the network flows D and the actual performance characteristics [C,M,Q], but not both. Of course, some models determine the location of activities and the demand and performance characteristics of the network jointly and consequently give rise to a L-G-P equilibrium, or even to more general equilibria.

B. Five transportation procedures - a reminder

More general equilibria may arise if one considers the multiple levels that can be distinguished within the transport component identified in Figure 1. These levels, shown in Figure 2, are reproduced from Florian and Gaudry (1983) and summarized here for the reader's convenience :

- the **demand procedure G** includes, in addition to the factors A, C and M defined above, the budget constraints on travel B;
- the **performance procedure P** has as output the vector of elements [C, M, Q] defined above, which depend on the demand level D and on the transportation supply conditions; the latter comprises infrastructure characteristics, including theoretical capacities, operational rules enforced by system managers, etc., denoted by T and user fee rates F;
- the **supply actions procedure S** determines the actions taken by the suppliers of transportation services and infrastructure in [T, F]. These actions depend on the suppliers' objectives O, their institutional environment E, their estimate of the state of the system ST and their resource costs, which are represented by a set $\{W(\tilde{T})\}$ of minimum cost combinations of resources that permit the realization of any output $\tilde{T}$ of transportation services (the brackets $\{.\}$ denote a set). The state of

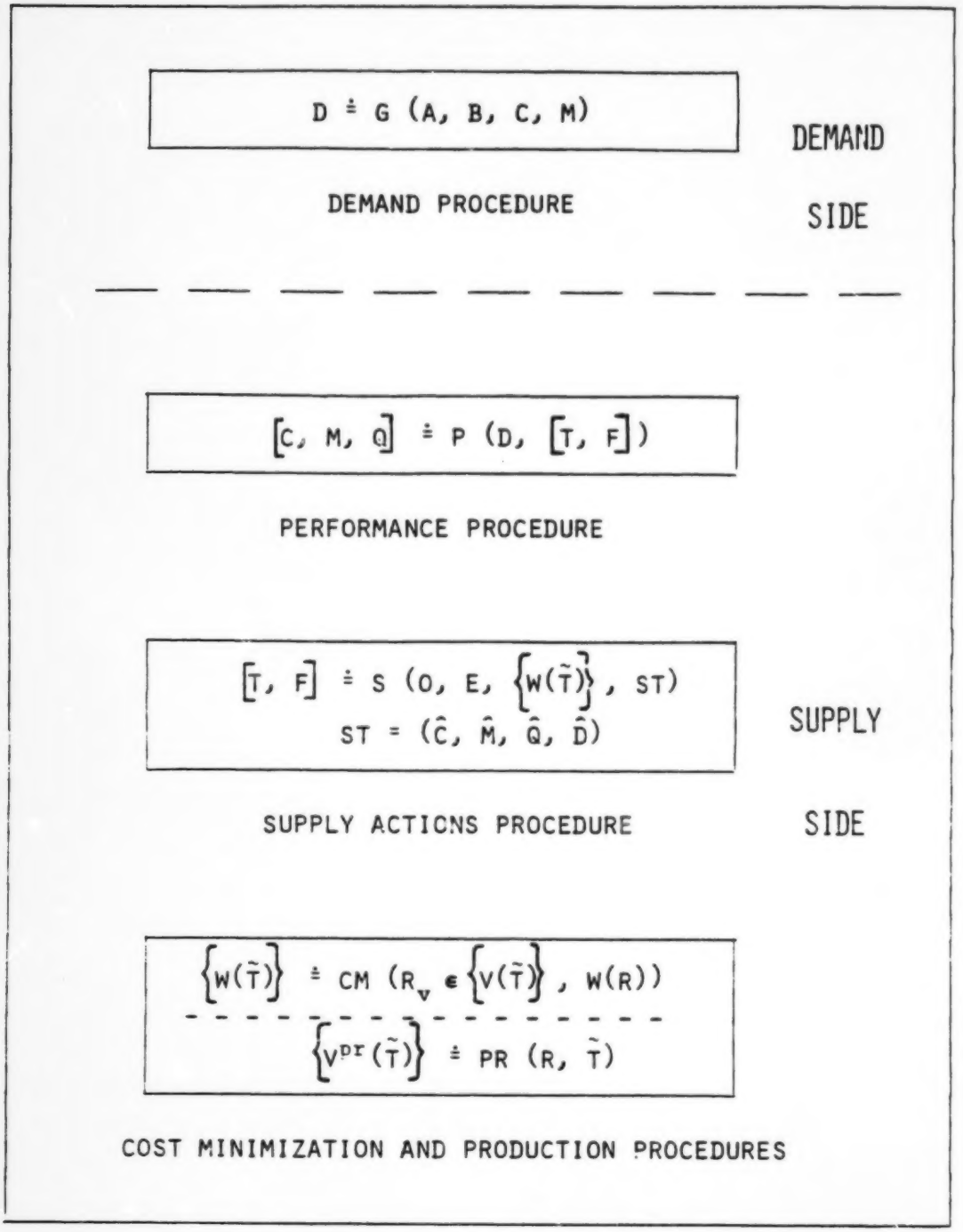
$D \doteq G\ (A, B, C, M)$
DEMAND
DEMAND PROCEDURE
SIDE
$[C, M, Q] \doteq P\ (D, [T, F])$
PERFORMANCE PROCEDURE
$[T, F] \doteq S\ (O, E, \{W(\tilde{T})\}, ST)$
$ST = (\hat{C}, \hat{M}, \hat{Q}, \hat{D})$
SUPPLY
SUPPLY ACTIONS PROCEDURE
SIDE
$\{W(\tilde{T})\} \doteq CM\ (R_v \in \{V(\tilde{T})\}, W(R))$
$\{V^{DT}(\tilde{T})\} \doteq PR\ (R, \tilde{T})$
COST MINIMIZATION AND PRODUCTION PROCEDURES

Figure 2. Transportation System Analysis : Five Procedures

the system ST is described by realized, estimated, or expected values of demand D, service levels C, user costs M and practical or effective capacities Q;

- the **cost minimization procedure CH** determines the least cost manners of combining the available resources R, given their prices W(R) and the set $\{V(\tilde{T})\}$ of feasible ways of combining these resources to realize $\tilde{T}$; this latter set includes the result of the **production procedure PR** that yields, among feasible input combinations, only those that are technically efficient, i.e. that use the smallest resource input to produce $\tilde{T}$.

C. The normative/descriptive and other casual distinctions

When we say that one fundamental dimension of model specification consists of deciding for the problem at hand what the levels are, we do not exclude other classification criteria : we believe that they are accomodated by our framework.

Consider for instance the fashionable distinction between equilibrium and disequilibrium approaches. As pointed out previously (Florian and Gaudry, 1983), our explicit use of a performance level is built to represent how queues (wait time) and perhaps black markets generate equilibria $D \leq Q$ in real markets. Our framework is general enough to incorporate, in the supply actions level, the actual process by which supply actions that imply queues are determined, as well as the process by which the length of these queues (and black markets) C could lead to modify the set of prices F and conditions T supplied. Of course if one really believed that queues and black markets do not clear the markets, one could build an appropriate excess demand/excess supply mechanism within the performance level of our framework and use [T, F] in the demand procedure instead of the market clearing outcome [C,M].

Similarly, although our framework is primarily of the descriptive kind, we do not purport to exclude the normative or design models often used to generate scenarios, or even models that directly use reduced form equations (in the econometric sense). Neither do we need to distinguish between models that build uncertainty into their formulation and those that do not. All require multiple levels, and notably a performance level, if they are to be credible.

3. THE "PERSPECTIVES" DIMENSION

Up to this point, we have presented a first basic dimension for the conceptual analysis and understanding of transportation planning and management situations, i.e. the dimension which describes the six **levels** or **procedures** L-G-P-S-CM-PR of transportation systems (including land use issues) and the interactions among them. To complete our conceptual framework, we will now introduce a second basic dimension which will help us to understand what we actually do, implicitly or explicitly, when building a transportation model. Also, this will help us to position such models with respect to each other and within a comprehensive taxonomy of the different categories of problems.

Broadly speaking, we may view transportation planning and management as a complex analysis and decision-making process characterized by the the multiplicity of relevant issues and decisions, the necessity of taking decisions at different levels of the organization with different planning horizons, the high interaction between all decisions and their various impacts, and the obligation to work in a constraining and diversified environment which has direct and indirect impacts on transportation systems as well as on decision-making.

Representing such complex processes in detail along with the enormous quantity of information involved will never be possible within a

single formal model or set of models. One has to manage within a hierarchical system and position oneself in relation to the above mentioned second dimension, i.e. a dimension which refers to the choices that one makes with regard to what should be considered as variable by opposition to what may be considered as fixed when dealing with a particular situation. (In discussing what is fixed or exogenous, and contrasting it with what is endogenous to the problem at hand, we shall assume that the simultaneous decision about the multiple levels involved is clear.). In other words, the second basic dimension is the one which refers to the various **perspectives** that one may choose when one is involved in real-life decision-making processes, i.e. processes where, as the case may be, there is more or less latitude for deciding between the type and amount of information regarded as fixed or exogenous and the type and amount of free, unfixed factors and decisions variables.

In order to clarify the discussion, and as discussed by others (see for instance Assad, 1980; Wong, 1984), we will identify three distinct but interrelated **perspectives** for transportation planning and management : **a strategic perspective STR, a tactical perspective TAC, and an operational perspective OPE.**

The reader will note that, in what follows, when describing these three overlapping or nested perspectives, we will refer to various notions such as "planning horizons", "levels of decision making", "levels of aggregation", "magnitute of investments", etc. However, in spite of the great and real interdependance between those notions and our concept of perspective, the latter should be more interpreted here as a generic concept dealing with the capacity:

i) to mentally view the levels L-G-P-S-CM-PR of transportation systems, or parts of them, in their true relations and relative importance,

ii) to decide (choose), at any particular level, between what is regarded as fixed or given and what is regarded as variable,

depending on the particular real-life situation and objectives in hand. Also, the concept of perspective is essential to make it clear that, in an extensive analysis and planning exercise, what may be regarded as exogenous when one adopts a particular perspective along the spectrum STR-TAC-OPE will possibly or necessarily regarded as variable since one adopts a different perspective. Thus, the crucial issue is actually to see any real-life situation or problem in its proper perspective, i.e. to position oneself within the resulting two-dimensional conceptual framework which is given a schematic picture in Figure 3, in a matrix form.

Note that such a conceptual exercise is not only an academic one : above all, it is essential for a comprehensive and sound understanding of the transportation planning and management activity, i.e. for a correct choice of the appropriate methodologies and techniques to be applied to analysis, problem solving and decision making.

Note also that our three-perspective STR-TAC-OPE classification should not be considered as a definitive one. In fact, one could define more than three perspectives, depending on the situation and context. However, it is still useful to develop the synthesis that we present in this paper.

The vertical dimension in Figure 3, i.e. the one which refers to the levels L-G-P-S-CM-PR of transportation systems, has been discussed in the previous section. As for the horizontal dimension, we have now to define more precisely the distinction that it pictures between our so-called strategic, tactical and operational perspectives.

To do so, we will take, as an example, the general case of a standard organization (or group of organizations with respective responsabilities) in charge of the planning and management of an urban transportation system. However, the reader should bear in mind that, for any particular transportation situation or problem (for instance the opening of a new

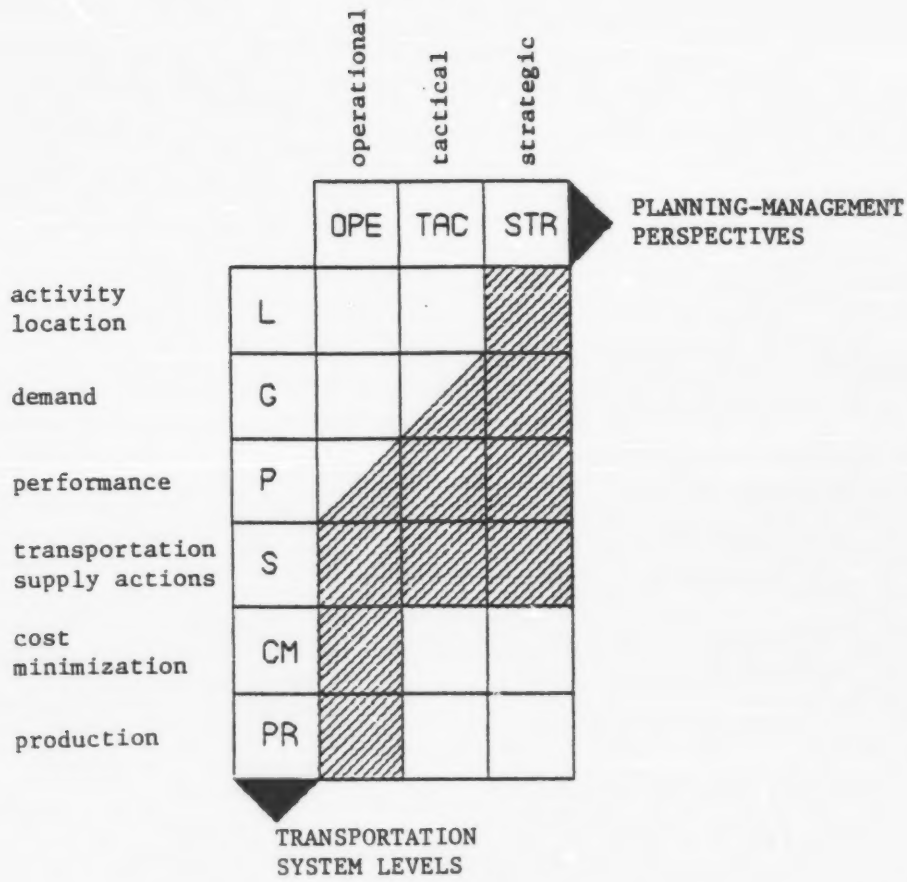

Figure 3. A two-dimensional conceptual framework

bridge, or the daily scheduling of bus activities), it is possible to define different perspectives, and in particular a strategic one, a tactical one and an operational one which are **differentiated essentially by the way one defines what is exogenous and what is endogenous.** At the limit, a strategic perspective would consider that almost everything relevant to the problem, including its environment, is variable and actually may change over time, thus requesting a somewhat aggregated point of view, while an operational perspective would consider that much more factors (and in particular the problem environment) are already fixed or given, and consequently exogenous.

Starting with the "largest and most aggregate" perspective, i.e the strategic one, analysis and decision making are applied to the definition of a supply policy for the organization, as well as to resource acquisition and major investment allocation over long time horizons. Analysis and decision making problems at this top level of the organization have system-wide long-lasting impacts and the planner has usually a very large degree of freedom since "almost everything" is possible. These problems deal with : network design and improvement, implementation of new service links, terminal capacity planning and location, fleet acquisition, etc. This strategic definition and analysis typically involves major capital investments, and it must take into consideration the state of the global transportation system, the possible variation of the transportation demand in relation with the demographic trends and the evolution of the land use pattern, etc. It must also consider the variability of the economic context (capital cost, inflation rate, cost of labour and energy, ...), the government context (transportation policy, regulation, support to some mode in particular, ...), and the evolution of the financial status of the organization.

Tactical issues, with a "narrower" perspective, concern questions which are raised regarding planning for the allocation of material resources of the organization in order to improve its efficiency or productivity. These issues have medium-term planning horizons and deal mainly with the efficient use of existing, given resources rather than the acquisition of major new ones. When adopting such a tactical perspective, the organization addresses problems such as frequency choice for each service considered, broad vehicle routing, definition of tariffs, maintenance planning (vehicle fleet maintenance, road maintenance, ...), etc. Of course, tactical analysis and decisions must also take into consideration the given financial capabilities of the organization and institutional

constraints such as regulation with regard to authorized variations in service levels and fares.

Finally, when dealing with the "most disaggregated and narrowest" perspective, i.e. the operational one, the organization has to solve its very short-term problems and organize in detail its day- to-day activities taking as fixed or given what is not strictly part of the questions to be answered. The production of timetables and the detailed routing and scheduling of vehicles and crews are examples of such problems relevant to an operational perspective. To analyze and solve those problems, the planner/manager will consider most parts of the transportation system and environment as fixed or given, including all constraints such as the average demands relevant to the problem (for instance origin-destination demands), the available human resources, the union rules, the detailed maintenance requirements, etc. On the other hand, he will have to take into consideration various unfixed matters such as all possible geometric configurations of bus lines and the weekly and daily variations of the transportation demands : such matters are usually irrelevant when dealing with the tactical or strategic perspectives as described above.

The objective of the above discussion is not to fix all kinds of transportation planning and management problems within a specific slot. As we said before, for **each** of these problems, it is possible to define a STR-TAC-OPE classification with regard to the possible perspectives one may adopt. For instance, the problem of real time traffic control at nodes of a street network would be classified as an operational issue in the example case of a standard organization discussed above, by opposition to "larger" problems such as the street network design. It remains that such a problem of traffic control involves by itself the definition of a "general" policy when regarded from a strategic or tactical perspective (what are the objectives and possible improvements with regard to congestion costs, which kind of technology to use for this end, etc.), while it

is actually an operational problem when one addresses, for instance, the problem of determining the green-orange-red phases of traffic signals at each intersection in a particular zone.

It is worth mentioning also that, due to the typically unbounded, uncertain and more relaxed nature of problems dealing with the analysis of transportation demand and land use-transport interactions, in contrast with more constrained and more well-defined operational issues that are typically dealing with supply actions bound by strict rules, most modelling efforts have been devoted as yet to the shadowed area in Figure 3.

To conclude, one may say that every transportation planning and management situation is potentially concerned with all levels of the conceptual system L-G-P-S-CM-PR and with the full hierarchy STR-TAC-OPE of strategic, tactical and operational perspectives. Along the vertical dimension in Figure 3, one is concerned with the description of the levels and interactions of transportation systems. Along the horizontal dimension, one is concerned with different possible perspectives and questions differentiated in scope, level of detail, time horizon, financial costs, level of decision making, etc., and, above all, differentiated in the identification of fixed or given matters on the one hand and variable matters on the other hand; in fact, along this horizontal dimension, from left top right, one is moving from "almost-everything- fixed-situations" towards "almost-everything-variable-situations".

4. TOWARDS A SITUATION PLANNING PARADIGM

It is clear that, in our view, the planning issues do not determine in a direct way which techniques to use; rather the situation and the problem at hand determine the models and techniques to use. In the terminology of the first section, PROP 2 is subordinate to PROP 1. Consequently, there is no rigid paradigm, but as many frames as required and each

and all require the identification of the levels involved and the necessary interactions implied by the horizon of the problem, as well as the choice of a particular perspective.

Before proceeding to expand on this basic premise, it is worthwhile to specify what is understood by a **situation.** It consists of a set of transportation systems planning issues defined in qualitative terms, a specific set of available analysis tools and the data sets that are available for the analysis. For the purpose of our discussion it is assumed that some limitation is always present regarding the analysis tools and the data available, this limitation being imposed by the time and resource constraints imposed in the given situation.

The paradigm that we seek, and name a "situation planning paradigm", is one that relates a given situation to the choices that are made regarding the levels L-G-P-S-CM-PR used and the planning management perspectives STR-TAC-OPE. It is not a prescriptive paradigm but rather a descriptive paradigm. In a given situation, once the transportation systems planning issues have been defined in qualitative terms, the analysis approach to be used emerges, by making choices regarding the possible time horizons of the analysis, the specific models and techniques used and the data to be used during the analysis. While these choices are made, when deciding what is fixed or given and what is variable in a modeling effort, one is actually choosing one or more cells of Figure 3, the two-dimensional conceptual matrix : in a given **situation**, the progressive determination or choice of analysis tools and data to be used, which imply essentially the determination of the endogenous/exogenous problem mix, is equivalent to **jointly** selecting (with reference to Figure 3) levels among L-G-P-S-CM-PR on the vertical dimension and perspectives among STR-TAC-OPE on the horizontal dimension. The process of making those choices may involve in some situations the specification of what is fixed or given and what is variable and the relevant relations, that is the choice of

certain cells, which imply an implicit choice with regard to the levels and perspectives dimensions. In other situations, the process of making choices will relate first to the levels and the perspectives, which imply certain cells, that is a particular specification of what is fixed or given and what is variable.

Without attempting to discuss in detail the morphology of transportation systems planning studies, it is worthwhile to observe that in most concrete cases, while a specific modeling approach emerges, iterations occur from one approach to the other, adapting at times positions regarding L-G-P-S-CM-PR and STR-TAC-OPE and deciding at other times what is fixed or given and what is variable. It is the knowledge and ingenuity of the transportation systems planning team that in the end determines the type of analysis to be carried out. Each situation is likely to be different, hence the situation planning paradigm described above. We recognize that in order to make the "best" choices for a given situation, the planning team should have access to all the planning tools available and all the data that would be required for their use, but this is unlikely to be the case in a given situation. The quality of the analysis and the quantitative input to the planning process are thus influenced by the means available and the choices made : reference to Figure 3 in any situation will make it evident where the analysis is located in the two dimensional conceptual framework for any choice made.

In order to illustrate partially the "situation planning paradigm", consider the transit agency that relies for all its analyses on the demand observed from origin-destination surveys that are carried out periodically. The agency limits itself to relatively short-term studies regarding the service that it offers to public transit riders, however it is concerned with offering this service at least cost. Clearly, the agency uses P, S and CM procedures with a TAC and OPE perspective. Changes in A will

be reflected in D as it is observed by the origin-destination survey, and are hence exogenous to the modeling approaches used, while C, M and Q are endogenous to the performance procedure used (usually transit network assignment with fixed demand), T and F are the output of the S procedure used and $\{W(\tilde{T})\}$ is the output of the CM procedure used (usually methods that minimize the human and physical resources used to offer the service).

By contrast, consider the transit agency that must plan its services in a rapidly developing urban area where origin-destination survey data would very rapidly be obsolete. In order to determine ultimately the service to offer, the agency is concerned with the development of the urban area and resort to an activity location procedure L that determines the activity pattern A as a function of the economic activities and prices (P_y, Y), the characteristics [C, M, Q] of the transport system resulting from a performance procedure and the demand D resulting from a demand procedure. This need would lead to considering all the shaded elements of the matrix of Figure 3, but not necessarily at the same time : once the new estimates for the demand D were determined by using the activity location procedure L and demand and performance procedures G and P, the remainder of the analysis is similar to that described above : instead of using observed demand, the same type of analyses will be carried out with the demand determined by using the activity location, demand and performance procedures. Clearly, a multitude of examples may be presented to illustrate the situation planning paradigm. The concept that we advance is simple and adaptive : for any given situation and given choices for the models and data to use, the two-dimensional conceptual matrix permits the classification of the analysis carried out by identifying the cells that correspond to the work carried out.

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